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Cryogenic mixed refrigerant cycle for FCC-hh

A unified solution for magnet and beam screen cooling

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Motivation

The current design of the cryogenic system features a conventional modified Claude cycle for the magnet cooling at 1.8 K and a Ne/He mixed refrigerant cycle for the beam screen and thermal shields cooling at 40 to 60 K. While the latter has certain advantages such as being highly efficient and oil free, it cannot be used below 25 K.

Each cycle has its own compressors, expanders and cold boxes. If both cycles are combined into one, higher overall efficiencies, reliabilities and lower investment cost can be expected.

Refrigerant

Applying a mixed refrigerant cycle for the liquefaction of helium requires the removal of the heavier component. A system that uses Freon 12 or Freon 13 was patented by R. Beddome in 1976 [1]. Both substances have the advantage of a rather high triple point which eases their removal. However, due to their enormous ODP and GWP they were banned by the Montreal protocol.

An efficient removal requires a low triple point pressure. At the same time the capital investment for the compressor can be reduced by a high molar mass of the ballast gas.

Oxygen is an atmospheric gas, does neither contribute to global warming nor to the depletion of the ozone layer. Its molar mass of 32 kg/kmol and a triple point pressure of 1.46 mbar make it an interesting ballast gas for this purpose.

Cycle design

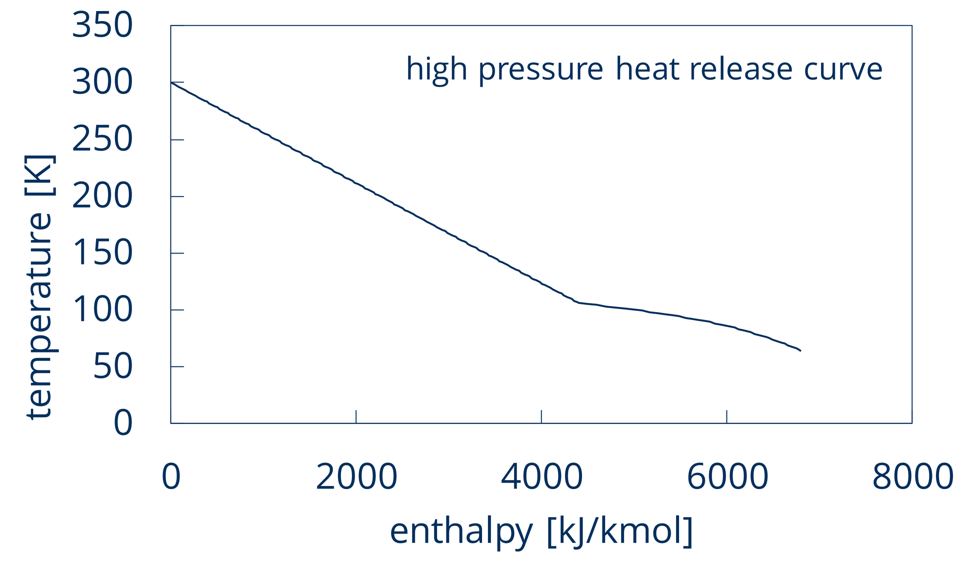
The central figure shows the upper part of the cycle which provides cooling for the beam screen as well as a high pressure helium stream at 20 bar and 55 K. It is a Claude cycle in which the refrigerant O_2 is expanded into an inert gas stream.

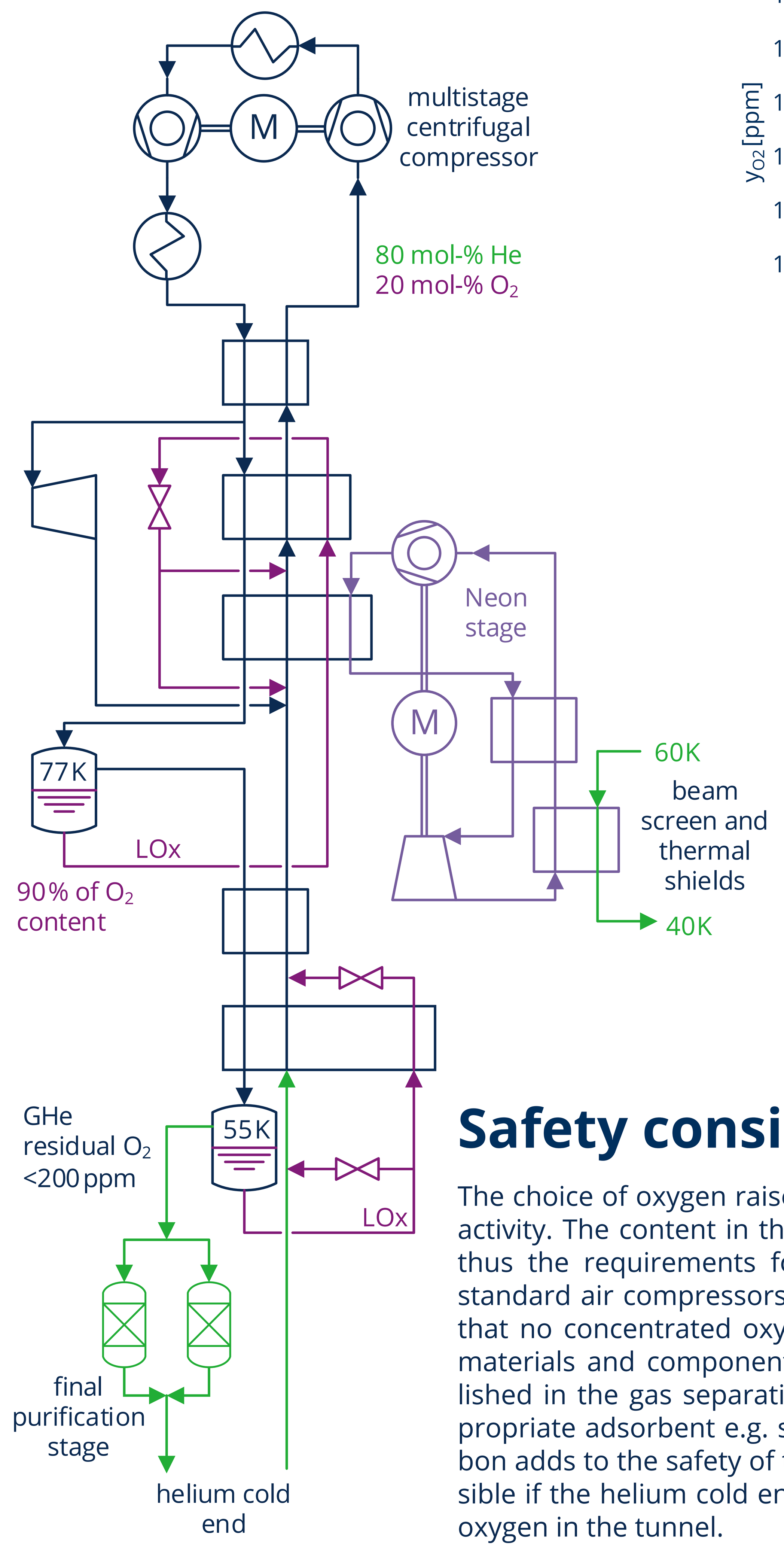
The heat release curve of the high pressure stream shown in the figure below has to be approached as close as possible with the low pressure stream.

At the lower temperatures (55 to 80 K), the JT effect is weak, therefore the expansion is applied at the same temperature with low mixing losses.

At higher temperatures up to the beginning condensation in the high pressure stream at 130 K, the JT effect is considerably stronger and thus the valves are in parallel to the heat exchangers.

The turbine is necessary due to the low enthalpy difference of the oxygen over the main compressor and enables to use the O2 not only as a ballast gas but also as a refrigerant - an important aspect to achieve higher efficiencies compared to conventional helium cycles.



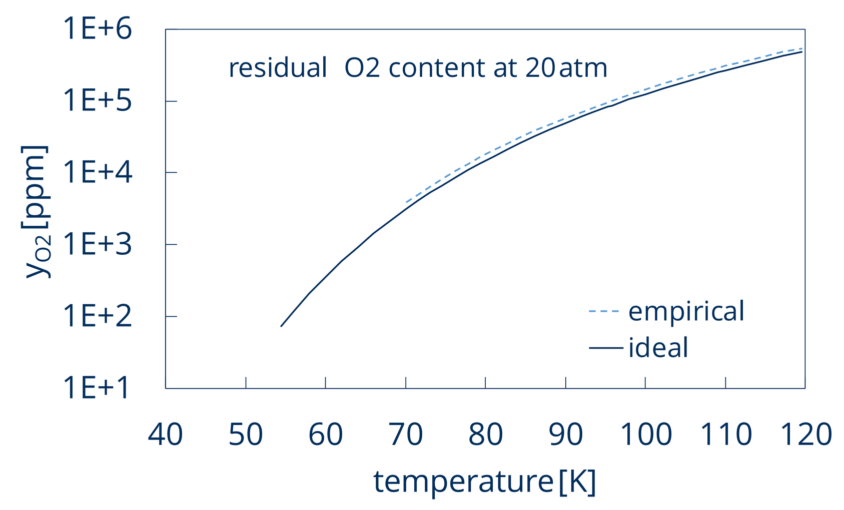


Helium purity

The requirements on the helium purity are quite high. This is to avoid any damage of turbines and clogging of valves.

The low triple point pressure of O_2 allows theoretically a residual oxygen content of 72 ppm. Experimental data for the triple point are not available, but the existing data from Herring [2] indicate that in fact high purities can be achieved, as shown below.

For the final purification stage, a pressure swing adsorption is foreseen to achieve residual O_2 contents in the order of a few ppm.



Neon stage

The O_2 part of the mixed refrigerant cycle is basically a Claude cycle with the peculiarity of a sliding evaporation temperature. The highest heat load can be adsorbed at temperatures of ca. 90 K to 130 K. Since the beam screens have to be operated at considerably lower temperatures, a neon stage is proposed. Due to the low temperature at the inlet of the compressor, a single compression stage is sufficient. This allows to integrate the turbine, motor and compressor into a single machine.

Safety considerations

The choice of oxygen raises some safety concerns due to its high reactivity. The content in the mixture is therefore limited to 20 mol-%, thus the requirements for the compressors are the same as for standard air compressors. The LOx is diluted inside the cold box so that no concentrated oxygen appears outside of the cold box. The materials and components for the handling of LOx are well established in the gas separation and welding industry. Choosing an appropriate adsorbent e.g. silica gel or zeolite instead of activated carbon adds to the safety of the cycle. Furthermore, a cut at 55 K is possible if the helium cold end is to be operated in the tunnel, avoiding oxygen in the tunnel.

Summary and outlook

A possible approach to an efficient and cost effective refrigeration for the FCC-hh has been shown. The proposed mixed refrigerant cycle efficiently provides cooling capacities at liquid helium temperatures and at higher temperatures. The capital expenditures can be reduced compared to separate cycles.

Currently under investigation are the optimal configuration of the JT valves for maximum efficiency, the distribution of the evaporating liquid in the heat exchangers and the dynamic behaviour.

References:

[1] *R. A. Beddome, "Low temperature refrigeration process for helium or hydrogen mixtures using mixed refrigerant," US3992167A, 16-Nov-1976.*

[2] *R. N. Herring, "Gas-Liquid Equilibrium Solubilities for the Helium-Oxygen System," University of Colorado, Colorado, 1964.*

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